Prospects for a Sustainable Cotton Industry in Tropical Australia Using Novel Crop and Pest Management

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ABSTRACT

Previous attempts, to grow cotton in the Ord River Valley region of tropical North Western Australia between 1963 – 1974 during the summer wet season failed due to a combination of crop management problems and high levels of insecticide resistance in Helicoverpa armigera. This paper describes a multi-disciplinary approach to research which aims to re-establish a sustainable industry using a novel management system. Components of the system include a shift to dry season (winter) cropping and a resistance management strategy, comprising the use of refugia crops for beneficial insect conservation and judicious use of selective insecticides. Pest management research focused on developing integrated pest management systems to complement transgenic cultivars expressing the Cry1A(c) delta-endotoxin from Bacillus thuringiensis (Bt). Control of the key pests, Helicoverpa spp, was greatly assisted by Trichogramma pretiosum which frequently parasitised more than 70% of eggs oviposited. Other lepidopteran pests were controlled successfully by Bt expression in the plants. Agronomic research investigated the effects of a winter growing season on crop development, yield and fiber quality. Over three seasons experimental yields for the top 10 cultivars averaged 2043 kg lint/ha, similar to the average summer grown experimental yields of 2069 kg lint/ha in temperate Australia. Cool night temperatures reduced fiber length by 1.27 - 2.54 mm (0.05 - 0.10 inches) at the optimum March-April sowing period compared with other sowing dates and the fiber length of the same cultivars when grown under summer conditions. Early crop growth was vigorous due to high temperatures, applying mepiquat chloride prior to squaring suppressed this growth. Areas of future research are discussed.

Introduction

The Ord River Irrigation Area in NW Australia (15.5°S, 128°E) was developed primarily for cotton production. The first crops were grown in 1963 and although good average yields of 1,082 kg lint/ha were achieved by 1971, yields had declined and by 1974, the average yield was only 660 kg lint/ha. This, combined with poor fiber quality and rising production costs, caused the industry collapsed.

One major cause of the industry's demise was the development of insecticide resistance by *Helicoverpa armigera* (Wilson, 1974). Although *H. armigera* was not a major pest initially, sprays targeted at other pests including *Spodoptera litura*, *Pectinophora gossypiella*, *Earias huegeliana* and others, conferred insecticide resistance to a range of organochlorine, organophosphate and carbamate insecticides. Spray records indicate that whilst only 12 insecticide applications per season were required initially, 21 sprays were needed in 1971 and to an average of 40 sprays in 1974 (Michael and Woods, 1980).

Genetic engineering techniques have now led to transgenic cotton cultivars containing specific insecticidal genes, the first to be commercialized being the Cry1A(c) delta-endotoxin from *Bacillus thuringiensis* (Bt). This gene technology has improved the prospects of establishing sustainable cotton production systems in high insect pressure environments, provided the technology is well supported by integrated pest management (IPM) and pre-emptive resistance management (Fitt, 1996), merged with cultural and agronomic practices. This paper describes research aimed at re-establishing a cotton industry in tropical NW Australia.

Methods

A multi-disciplinary approach was required to design a sustainable production system to avoid heavy reliance on broad-spectrum insecticides and the associated impacts of resistance and residues. The elements of the envisaged new system of production are contrasted with the 1970's industry in Table 1.

Major benefits from the proposed change to winter cropping relate to pest management. In particular, winter cropping substantially avoids the high pest abundance of *Helicoverpa armigera, H. punctigera, S. litura, P. gossypiella* and loopers that characterize the summer wet season. Additionally, crop management

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logistics are facilitated by consistent, dry winter weather.

Pest management research

The focus of research in 1996 and 1997 was on transgenic cultivars (containing the INGARD® (Bt) gene by Monsanto). INGARD® efficacy in the field and comparative assessments of IPM systems were evaluated in replicated on-farm trials. Plot were large (10 – 20 ha) to simulate commercial cropping and to generate biological activity within plots with minimal edge effects. The okra-leaf Siokra L23 and its transgenic (INGARD®) equivalent Siokra L23*i* were the standard cultivars during both seasons.

Components of an IPM system evaluated in the trials included strips of either lucerne or niger (about 6% of plot area). These crops were selected because of their reputed ability to both attract and trap minor pests such as mirids (*Creontiades dilutus*) and to act as reservoirs of beneficial insects (Mensah and Khan, 1997). In some cases, an "insect food spray" (Envirofeast®) was applied in accordance with a schedule provided by the manufacturer (Rhone Poulenc), to attract beneficial insect species to crops.

Pest and beneficial insect abundance in crops was measured by direct field counts and by suction sampling. Field counts followed the standardized sampling procedure detailed in the computer based decision support system entomoLOGIC (Dillon and Fitt, 1995). This program was also used to determine pest thresholds but the specific treatments applied varied according to the pest management system being evaluated. Suction sampling utilized an Echo® blower/vac machine with a flow rate of approximately 10 L/second. Each plot measurement comprised five, 20 m row sampling units and the resulting collections were returned to the laboratory for species identification and recording.

Specific counts of the *Helicoverpa spp.* egg parasitoid *Trichogramma pretiosum* were taken weekly. A minimum of 100 *Helicoverpa* eggs were collected from each experimental plot and confined individually to wells within a covered tissue culture tray. The fate of the eggs was recorded to measure parasitoid activity within each crop treatment.

Agronomic research

The tropical dry season is the reverse in terms of temperature and daylength to the typical summer season in temperate cotton growing areas. Planting occurs in hot rather than cool conditions, boll development is in cool rather than warm weather, and ripening occurs during extremely hot rather than cooling conditions.

A 'desk-top' analysis prior to the commencement of field research in 1994 identified key questions concerning crop adaptation in the winter season. Firstly, the effect of cool to cold night temperatures and reduced total light during boll development on growth, development and fiber quality. Secondly, to what extent high early season temperatures would lead to vigorous or rank growth prior to flowering. Thirdly, confirmation that there would be sufficient time to grow, harvest and remove stubble during the dry season. Heat unit analysis suggested this would be possible but timing would be crucial, requiring prompt sowing after the wet season combined with sufficient picking and stalk removal capacity.

Development of basic cultural practices that would enable larger scale IPM trials to be grown with minimal agronomic limitations was needed. Research was required into suitable cultivars, optimal plant nutrition, irrigation scheduling and the role of growth regulators. A current objective is to integrate the extension of agronomic and pest management research.

Results and discussion

Pest management research

INGARD® efficacy: Two years of field evaluations at Kununurra have demonstrated the efficacy of INGARD® cultivars against a range of lepidopteran pests for most of the season. Pests almost totally controlled included pink bollworm (*Pectinophora gossypiella*), rough bollworms (*Earias huegeliana* and *E. vittella*) and cotton loopers (*Anomis flava* and *A. planalis*).

Helicoverpa spp. was effectively controlled for most of the season (Figure 1). However, INGARD® efficacy is greatest early in the season and declines when the plant approaches full boll load, thus there is a requirement for additional late season *Helicoverpa* control. (Larval numbers in the conventional cotton were suppressed by 10 insecticide applications during this trial).

IPM evaluations: The development of an IPM system to complement transgenic cultivars is essential to sustainable production. An effective IPM system reduces the risk of pests developing resistance to Bt by lowering the number of pests surviving and / or being exposed to the transgenic crops. IPM may include trap and refuge crops to minimize the necessity for insecticide use whilst providing a source of beneficial insects that could be recruited to assist in pest control.

During 1996 and 1997, a range of IPM systems for transgenic cotton were compared with conventional cotton and conventionally managed transgenic cotton. Systems were selected for evaluation on the basis of IPM research elsewhere in Australia (Mensah, 1997) and adapted to local crop management practices. The results from these trials are summarized in Table 2.

The results show the lepidopteran pest control of INGARD® with or without supporting IPM (Table 2). All systems based on transgenic cultivars required an average of between 1.75 and 3 insecticide applications to control *Helicoverpa spp* compared with 7.5 sprays on conventional cotton. No conventional cotton was produced in 1997 but, in trials conducted during the preceding 3 years, between 10 and 15 insecticide applications were necessary. Thus a significant reduction in pesticide requirement of at least 70% is inferred through the field performance of INGARD®.

In both seasons all IPM treatments achieved adequate yields that were similar to traditionally sprayed conventional and INGARD® cotton. There was also a trend towards a lower insecticide requirement for IPM cotton than for stand-alone INGARD® fields. Coincident with the lower spray requirement in IPM plots is a trend for higher numbers of predatory insects as shown for three systems in Figure 2 for 1996. Although predatory insect populations fluctuated during the season, there was a trend during the mid and late season for numbers to be higher in the IPM treatments that included lucerne strips and / or the insect food spray Envirofeast®. A wide range of predatory insect fauna was identified in the samples. The most common were lady beetles (*Coccinella transversalis* and *Coelophora sp*), hover flies (Syrphidae) and lacewings (*Chrysopa spp*).

Insect parasitoids were also recorded from suction samples as summarized in Figure 3. Surprisingly, parasitoid numbers tended to be comparatively higher in sprayed INGARD® crops (without supporting IPM systems) during the early and mid-season. The lucerne strips being highly attractive to pests and beneficial insects early in the season, could explain this. Late in the season, the reverse appears to occur and parasitoid abundance increases in cotton with lucerne strips. Lucerne may act as a reservoir of beneficial insects that move into the cotton when suitable prey and food resources become available. This timing is important because late in the crop cycle, INGARD® efficacy declines and beneficial insects become of most value to an IPM system.

Trichogramma pretiosum abundance: *Trichogramma pretiosum* is recognized as the most important of parasitoids limiting the impact of *Helicoverpa spp* in NW Australia (Pinto *et al.*, 1993). The parasitoid often infests 60% or more of *Helicoverpa* eggs and can therefore limit the damage potential of the pest. In terms of resistance management in INGARD® cotton the wasp reduces the hatch rate of *Helicoverpa* eggs

boll growth periods of later pollinated flowers and ensured a prompt harvest.

Interaction with pest management research: To be compatible with the IPM strategies being developed, some plant fruiting structure compensation for insect damage is required. Removal of early fruit by mirids has been a common occurrence in our experiments. Plant mapping data collected from a range of experiments in the past three seasons has found that, where fruit is removed prior to flowering and there is minimal loss of late fruit, yields are rarely affected

and consequently reduces the numbers of caterpillars exposed to Bt protein toxins.

In 1996 and 1997, the level of *Trichogramma* parasitism was measured in a range of pest management systems for INGARD® cotton. A summary of results for 1997 is shown in Figure 4. Levels of activity fluctuated during the season and between the various pest management situations. Generally, egg parasitism levels were approximately 60% with the best level of 92% of eggs being recorded in early May. An understanding of the ecology of *T. pretiosum* is an urgent priority.

Agronomic research

Crop adaptation: In the absence of commercial ginning facilities, small plot experiments were used to gather yield and lint quality data. Over three seasons, yields were found to be comparable with summer grown crops in temperate Australia (Table 3). Therefore, we anticipate long term commercial yields to be similar to current national averages of 1600 kg lint/ha with top yields of 2200 kg lint/ha.

Fiber length was reduced by an average of 2.54 mm (0.1 inches) compared with the same cultivar grown in SE Australia. No other fiber quality parameters were significantly changed due to the winter season. Figure 5 confirms research elsewhere that fiber length appears to be proportional to night temperature during flowering (Gipson and Joham, 1968). The average minimum temperature during flowering at Kununurra is 14$_o$C, therefore, price discounts for fiber length could be expected in many seasons. Varietal selection is considered to be the main solution to this problem for the future.

As expected, early growth was vigorous, compared with that of temperate summer grown crops. Research shows that pre-squaring applications of mepiquat chloride (15.2 g ai / ha) suppresses early growth and where early boll retention is reasonable (> 30%), final plant height can be similar to temperate crops. Three seasons of research found no yield penalty in untreated control plots that were usually very tall (Figure 6).

Sowing from mid-March to mid-April was optimal for yield and permitted harvest from mid-September to early-October, well before the likely arrival of wet season rains in November. Synchronous boll opening due to rising end-of-season temperatures reduced the

(Figure 7). This is because the crop has compensated for early fruit loss by producing additional fruiting branches, a situation that in southern Australia or the USA would result in later maturity. However, in NW Australia due to the greater synchrony in ripening between early and late fruit due to rising the season temperatures, delays in maturity are minimized.

Further research is required to evaluate compensation under other types of pest damage such as removal of the mainstem terminal bud and the interaction of damage with growth regulator use.

Conclusions

Transgenic cotton cultivars, containing the INGARD® (Bt) gene, show great promise in tropical NW Australia. Although the gene does not provide total control of *Helicoverpa armigera* and *Helicoverpa punctigera* throughout the season, the use of trap and refuge crops as components of an integrated pest management (IPM) system assist in control. The *Helicoverpa spp* egg parasitoid, *Trichogramma pretiosum*, is the most important beneficial insect in the cotton ecosystem but its ecology is not fully understood.

Agronomic research has shown that some cultivars can be adapted to a tropical winter production system. Experimental yields and fiber quality parameters are similar to those produced in temperate Australia. However, cool night temperatures after flowering reduce fiber length and additional varietal selections are required to overcome this problem.

Winter cropping would avoid many pest and agronomic difficulties posed by a tropical summer system. Transgenic cultivars, grown with supporting IPM systems, offer the opportunity for sustainable cotton industry development in this region.

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Table 1. Key elements of a novel cotton production system contrasted with the previously unsuccessful system of the 1970's.

1970's INDUSTRY	NEW INDUSTRY
Summer cropping (wet season)	Winter cropping (dry season)
Conventional cultivars	Transgenic cultivars
Broad spectrum insecticides	IPM systems
No pesticide resistance management	Pre-emptive Bt resistance management

Table 2. The mean lint yields, number and purpose of insecticide sprays in the IPM trials, Kununurra, 1996 and 1997.

Treatment[1]	Mirid sprays	Aphid sprays	*Helicoverpa* sprays	Total sprays	Yield Kg lint/ha
1. Siokra L23*i* alone	2.13	0.25	2.25	4.63	1,584
2. Siokra L23*i* + Envirofeast® + lucerne	1.48	0.15	2.	3.66	1,610
3. Siokra L23*i* + lucerne	1.25	0.13	1.75	3.13	1,756
4.# Siokra L23*i* + niger	1.5	0.25	3.0	4.75	1,630
5.* Conventional cotton + Envirofeast® + lucerne	3.0*	0	7.5	10.5	1,594

1 all treatments were sprayed when entomoLOGIC thresholds were reached
* includes rough bollworm as a target pest (grown 1996 only)
\# grown 1997 only

Table 3. Comparison of small plot lint yields (Kg/ha) in Australia. Summer grown are the mean of 17 cultivar trials in 1996/1997, winter grown is the mean of 3 years 1995 - 1997 inclusive.

	Summer grown temperate	Winter grown tropical
Average Top 10 Varieties	2,069 Kg/ha	2,043 Kg/ha
Best	2,529 Kg/ha	2,483 Kg/ha
Range	1,650-2,529 Kg/ha	1,829-2,483 Kg/ha

Figure 1. The field efficacy of the INGARD® gene (in cultivar Siokra L23) controlling *Helicoverpa spp* at Kununurra, 1996.

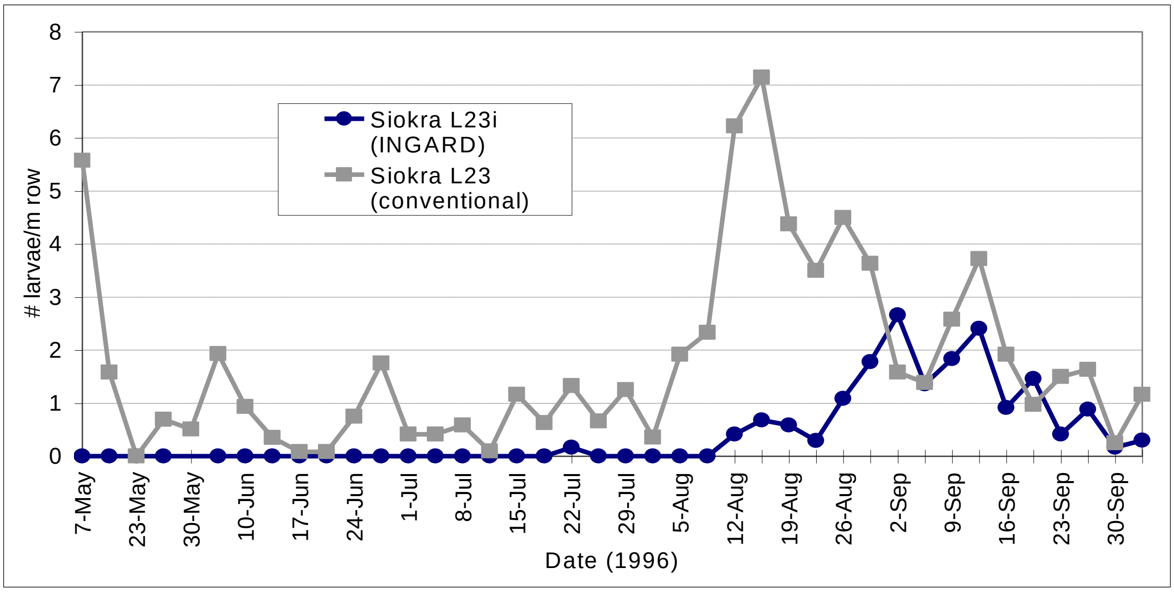


Figure 2. Mean number of predatory insects /m row collected by suction sampling from INGARD® cotton grown in different management systems, Kununurra, 1996.

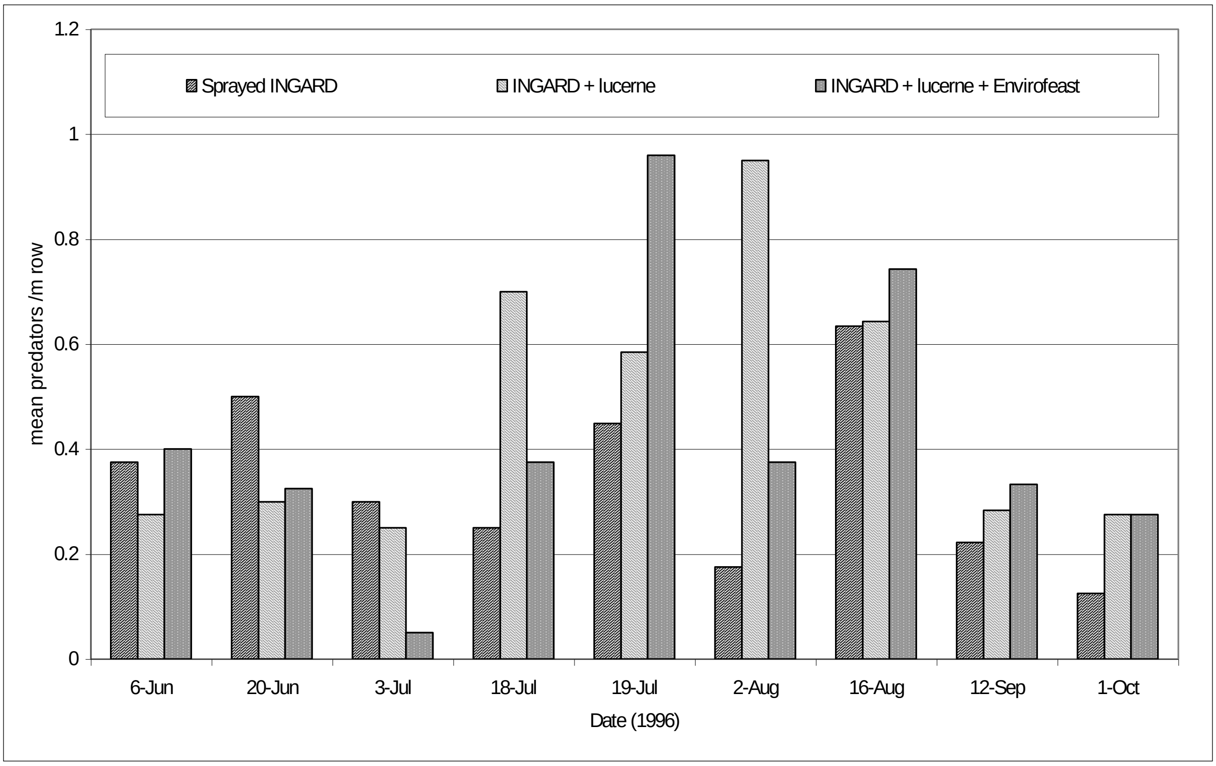


Figure 3. Mean number of insect parasitoids /m row collected by suction sampling from INGARD® cotton grown in different management systems, Kununurra, 1996.

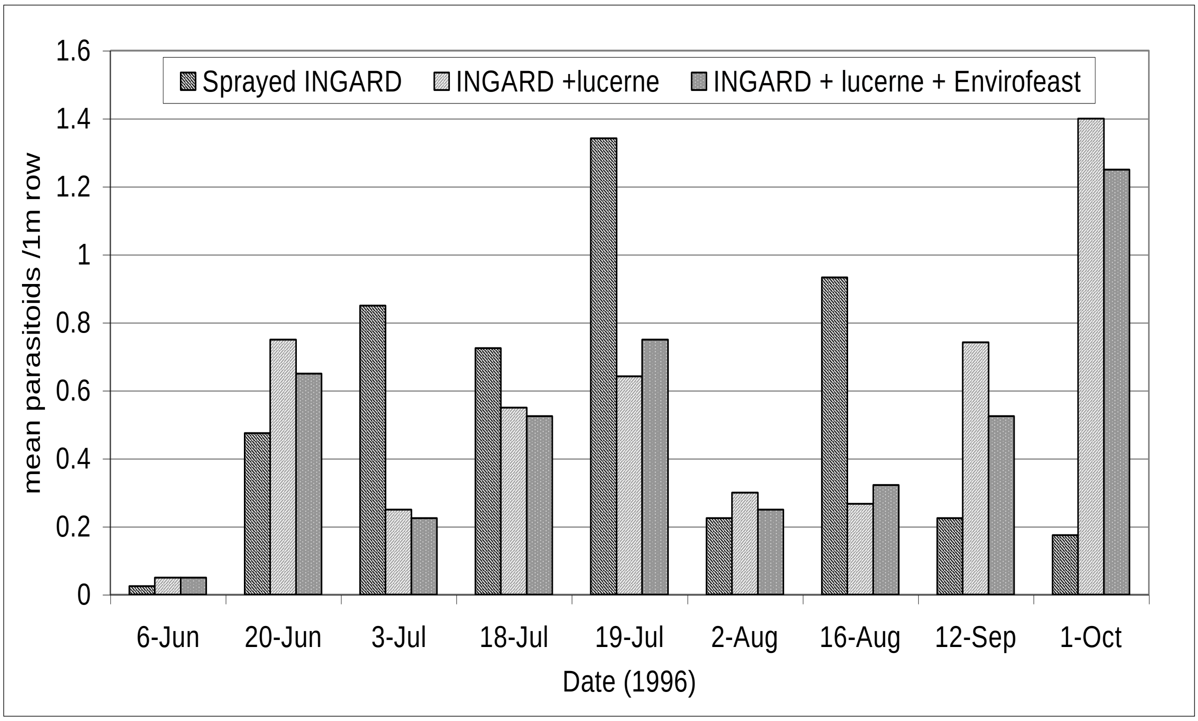


Figure 4. The percentage of *Helicoverpa spp* eggs parasitised by *Trichogramma pretiosum* in a range of pest management systems at Frank Wise Institute, Kununurra, 1997.

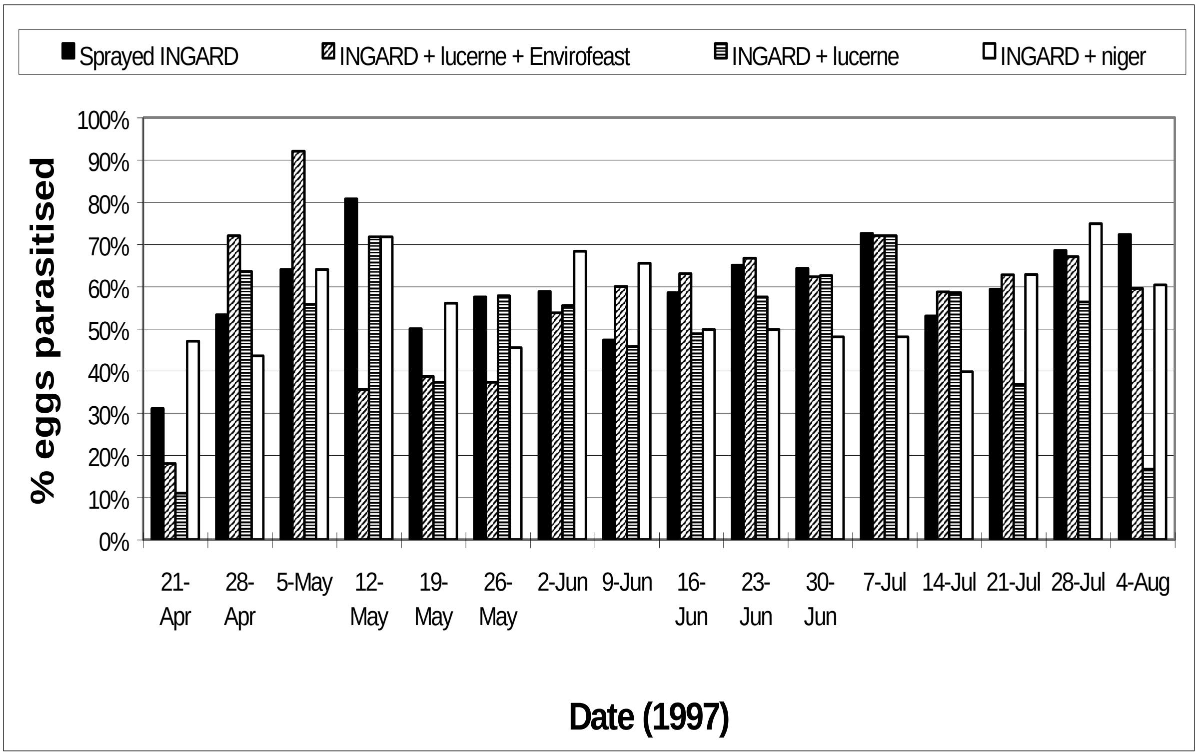


Figure 5. The effect of mean night temperature during the first 20 days after flowering on fiber length (mean of two INGARD® cultivars) at Kununurra in 1996.

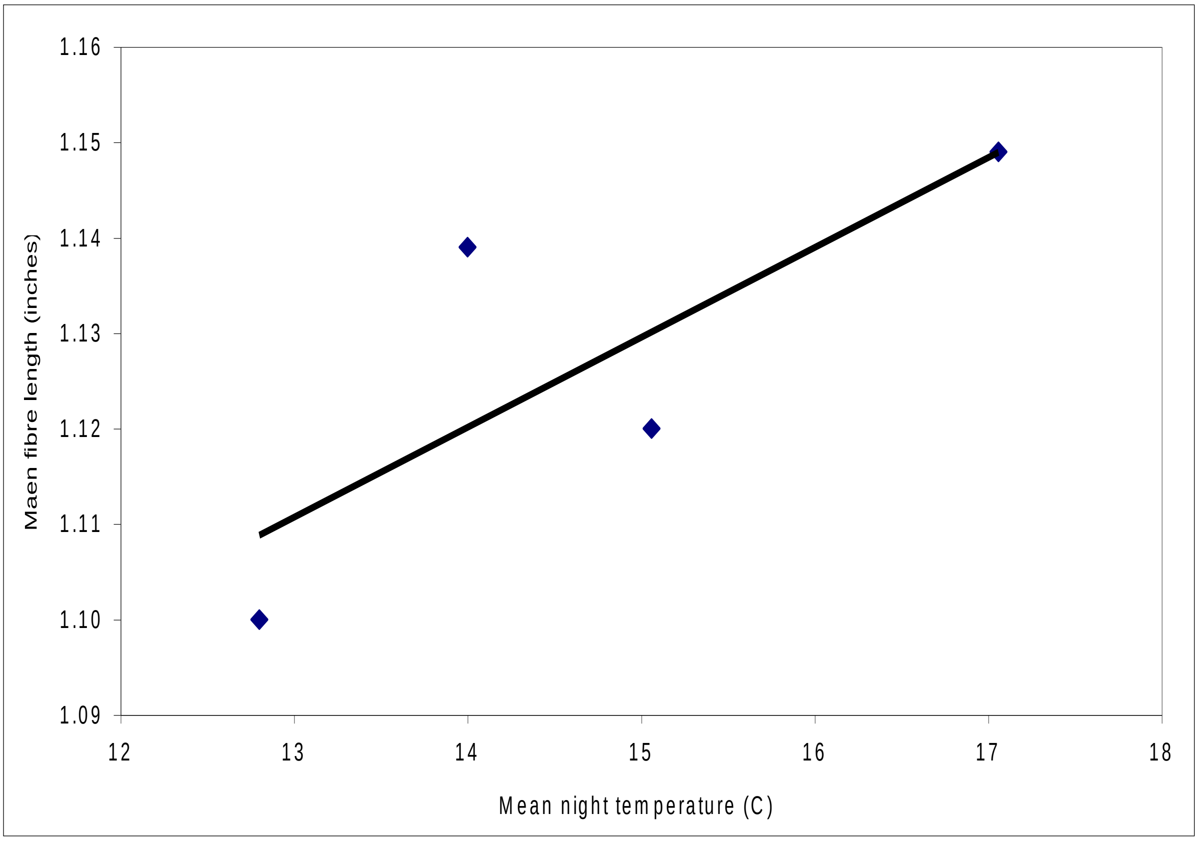


Figure 6. Comparison between crop vigour in tropical Australia winter sown and the standard relationship used for Acala cotton in California (adapted from Constable 1996). Control = no MC (mepiquat chloride), grown in 1995; MC at node 7 = 15.2 g ai/ ha of MC applied when 6 to 7 mainstem nodes where present, grown in 1997.

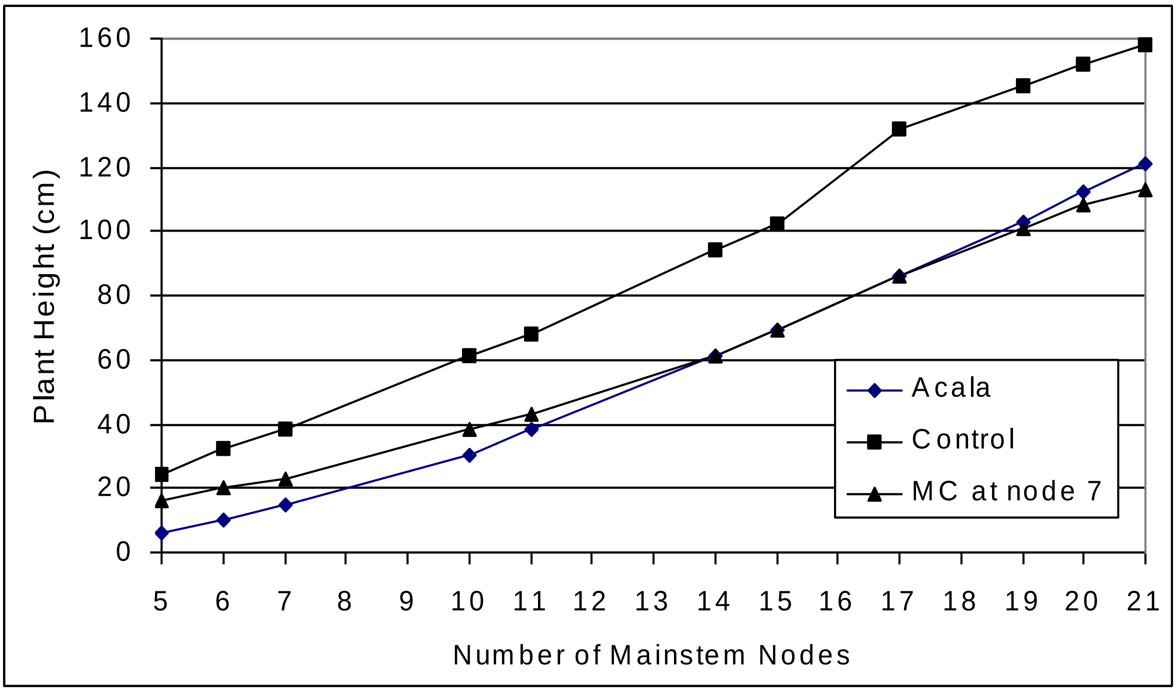
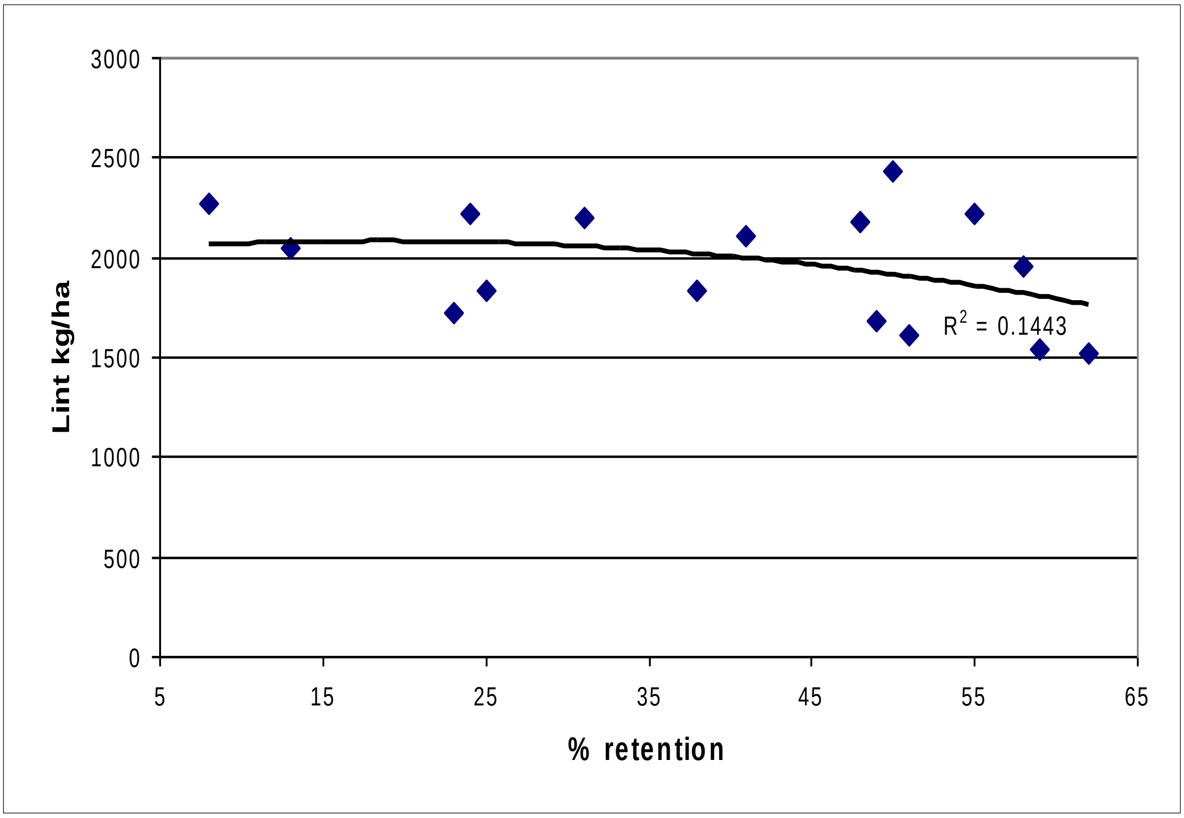


Figure 7. The absence of a relationship between boll retention (%) of first position bolls in the lowest five fruiting branches and yield for the cultivar Siokra L23 grown in winter in tropical Australia. Retention was measured from 40 plants per treatment in experiments grown in 1995,



1996 and 1997. Yield was determined by machine harvest.